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FOREIGN TRIP REPORT

ORNL/FTR-3449

DATE: October 27, 1989

SUBJECT: Report of Foreign Travel of Prof. Jorge L. Sarmiento, Princeton University (ORNL Subcontract No. 19X-SC166C)

TO: Alvin W. Trivelpiece

FROM: Prof. Jorge L. Sarmiento

PURPOSE: To attend the Third International Conference on Analysis and Evaluation of Atmospheric CO_2 Data Present and Past and to present two papers: "On the Role of the Oceans in Determining Atmospheric CO_2," and "3-D Ocean Models of Anthropogenic CO_2 Uptake." To attend a workshop of the International Geosphere-Biosphere Program Panel 5 on modeling.

SITES VISITED: 10/15-21/89 Hinterzarten, Federal Republic of Germany

ABSTRACT: J. L. Sarmiento presented two papers at the Third International Conference on Analysis of Atmospheric CO_2 Data Present and Past. The first paper, "On the Role of the Oceans in Determining Atmospheric CO_2," concerned primarily the work that is being carried out in collaboration with M. J. R. Fasham on the development of ecosystem models for predicting the possible role of changes in the biological cycling of carbon in affecting atmospheric CO_2 levels. The second paper, "3-D Ocean Models of Anthropogenic CO_2 Uptake," concerned the work being carried out in collaboration with U. Siegenthaler on simulating the uptake of anthropogenic CO_2 by the oceans in the absence of any changes in the biology. Sarmiento also met with Siegenthaler to plan a future series of oceanic anthropogenic CO_2 uptake experiments and listened to a series of presentations on recent work in this area, of which the atmospheric measurements and models were of considerable value. The International Geosphere-Biosphere Program Panel 5 meeting was held in order to work on the draft of a plan for modeling as part of this program.

The work is conducted by Princeton University, United States, (Prof. J. L. Sarmiento, Principal Investigator) for the Department of Energy (DOE) Energy Systems Program managed by Oak Ridge National Laboratory.

Report of Activities

The purpose of the trip was to present new results from research that has been carried out at Princeton University over the last year in collaboration with co-investigators M. Fasham and U. Siegenthaler and to have the opportunity to get up to date on research in the area of the cycling of anthropogenic CO_2. The meeting lasted five days, with sessions on (a) ice core measurements, (b) causes of glacial-interglacial CO_2 variations, (c) atmospheric observations, (d) isotopes in the carbon cycle, (e) exchange atmosphere-land biota, (f) land biota, (g) marine biota and the carbon cycle, (h) oceanic pCO_2 and air-sea exchange, and (i) ocean modeling and oceanic processes, with a poster session covering several of these topics.

The first presentation by Sarmiento was "On the Role of the Oceans in Determining Atmospheric CO_2." A brief overview was given of mechanisms by which changes in the natural cycling of carbon in the oceans might lead to rapid changes in the level of atmospheric CO_2 which are of the same order of magnitude as the anthropogenically induced atmospheric transient and which might also serve to explain the natural changes observed in ice cores. These include processes such as deep convective overturning and biological uptake in high-latitude deep water formation regions, changes of which can lead to pCO_2 levels ranging from approximately 165 ppm to 425 ppm, compared to a preindustrial value of 280 ppm; and shifts in the distribution of alkalinity in the oceans which might result from changes in surface productivity, and which can lead to pCO_2 changes ranging from approximately 265 ppm to an excess of 1100 ppm, at which point surface waters become undersaturated with $CaCO_3$. A prediction of how the natural ocean carbon cycle might respond to climate change requires development of predictive models of ocean circulation, chemistry, and biology. A review was given of progress at Princeton, in collaboration with M. Fasham of the Institute of Ocean Sciences in Wormley, on the development of the necessary upper ocean biological models. Our initial aim is to develop generic ecosystem models that are able to simulate the behavior of the biology with respect to the cycling of nitrate in the euphotic zone of the water column. A comparison of our first model results, which are for the North Atlantic, with nutrient and satellite Coastal Zone Color Scanner (CZCS) observations show that our present simulations have too high phytoplankton in the equatorial region, too low in the subtropics, and too high in the higher latitudes. All of these problems can be linked to problems in simulating the upper ocean physics which also manifest themselves in a consideration of the heat budget. The model does an excellent job of simulating the development of the spring bloom, but then tends to collapse too early in the year, probably due to problems with the biological ecosystem model. Research is under way to improve both the physics and the biology.

The second presentation by Sarmiento was "3-D Ocean Models of Anthropogenic CO_2 Uptake," which discussed a series of simulations of anthropogenic CO_2 uptake by the oceans for the period 1750 to the present with the world ocean primitive equation model of Toggweiler et al. (1989). The boundary condition for the simulations is provided by the combined

Siple ice core and Mauna Loa atmospheric CO_2 records as analyzed by Siegenthaler and Oeschger (1987). Between the middle of 1958 and the middle of 1986, the total increase in carbon in the atmosphere determined from the observations is 66.7 Gt, and the increase predicted in the model ocean is 38.0 Gt, for a total of 104.7 Gt. The fossil CO_2 release estimated by Rotty and Masters (1985) for the same time span is 115.6 Gt. The oceanic uptake would thus have to increase by 28.7% in order to account for just the fossil CO_2 production. The bomb radiocarbon simulation carried out with the same ocean model by Toggweiler et al. (1989) underpredicts radiocarbon uptake by almost 19% relative to Geosecs observations, due, at least in part, to a sluggish exchange between the surface and deep ocean. This suggests that a more realistic ocean model (one with a more rapid surface to deep exchange) will take up more CO_2, but at this point we must conclude that it is very unlikely that the ocean sink can account for all of the fossil CO_2 signal as well as a major deforestation source such as is postulated to exist. We are in the process of exploring the sensitivity of this result to a variety of additional factors such as the way in which we parameterize the ocean chemistry and the role of seasonality. A first result shows that the sensitivity of the fossil CO_2 uptake to the gas exchange rate is negligible: a 20% increase in gas exchange gives a 2.5% increase in CO_2 uptake, and a 100% increase in gas exchange gives only an 8.9% increase in uptake.

Discussions with Siegenthaler were aimed at developing a strategy for the next set of simulations of oceanic uptake of anthropogenic CO_2. The major points addressed by these discussions are the fact that our present perturbation approach is with a model that is nonseasonal, and it makes use of a simplified chemistry. We developed a strategy for using a seasonal model, the development of which has just been completed at Geophysics Fluid Dynamics Laboratory (GFDL) Princeton, for CO_2 uptake experiments which involves determining an initial alkalinity concentration from maps of measured values and an initial total carbon concentration by fixing atmospheric CO_2 at the preindustrial value and allowing it to invade the ocean until equilibrium is reached. This would account for the physical and chemical effects on the carbon system but not for the biology. Later on we will use the ecosystem models being developed at Princeton in collaboration with Fasham to include the effect of biology.

The meeting provided the opportunity to meet Roger C. Dahlman, U.S. Department of Energy, Atmospheric and Climate Research Division, Office of Health and Environmental Research, who has recently been placed in charge of carbon cycle research at the Atmospheric and Climate Research Division, DOE, and to discuss with him the continuation of our project, which has been supported from the DOE Energy Systems Program managed by Oak Ridge National Laboratory.

Extensive discussions were carried out with I. Fung, as a follow-up to a presentation by P. Tans, regarding the difficulty being encountered in the Goddard Institute of Space Studies (GISS) atmospheric model of transporting as much CO_2 to the Southern Hemisphere as appears to be required by the ocean models. Fung makes a convincing case for taking these atmospheric

models seriously. A simple box model developed by Sarmiento with Fung at the meeting suggests a way out of the problem:

1. There may have been a large preanthropogenic Southern to Northern Hemisphere CO_2 flux on the order of 1.2 Gt per year, with release from the Southern Hemisphere ocean being balanced by uptake by the Northern Hemisphere ocean.

2. A major implication of this is that the Northern Hemisphere ocean should be taking up on the order of 2 Gt of carbon per year at the present time. This large flux should be reflected in the air-sea pCO_2 gradient, which needs to be an average over the entire Northern Hemisphere ocean on the order of 22 ppm; larger if only a fraction of the Northern Hemisphere ocean is involved. Such an average air-sea gradient has not been observed, but it is not clear that the observations have sufficient spatial and temporal coverage as yet. The need for such measurements is strongly suggested by this result.

The above results also suggest that it would be of considerable value to carry out a simulation of the atmospheric CO_2 transport with a much more highly resolved model than the GISS model, which needs to have a large diffusion correction made to it due to the fact that it does not simulate a large enough interhemispheric exchange rate. Such models exist at GFDL/Princeton, and planning for an appropriate experiment has begun.

On the final day in Hinterzarten, Sarmiento attended a drafting session of the International Geosphere-Biosphere Program Panel 5 that was led by B. Bolin with the aim of developing a draft of a long-term plan. Sarmiento contributed a discussion of the role of the oceans in the carbon cycle and helped to prepare a first draft for this purpose.

References:

Rotty, R. M., and C. D. Masters. 1985. Carbon dioxide from fossil fuel combustion: Trends, resources, and technological implications. In: Atmospheric Carbon Dioxide and the Global Carbon Cycle, ed., J. Trabalka, DOE/ER-0239, U.S. Department of Energy, Carbon Dioxide Research Division, Washington, D.C. 20545, pp. 63-80.

Siegenthaler, U., and H. Oeschger. 1987. Biospheric CO_2 emissions during the past 200 years reconstructed by deconvolution of ice core data. Tellus, 39B, 140-154.

Toggweiler, J. R., K. Dixon, and K. Bryan. 1989. Simulations of radiocarbon in a coarse-resolution, world ocean model II: Distributions of bomb produced ^{14}C. J. Geophys. Res. (in press).

APPENDIX

Trip Itinerary

October 14, 1989	Depart Princeton/New York en route to London, England
October 15, 1989	Depart London en route to Zurich/Hinterzarten
October 21, 1989	Depart Hinterzarten en route to Zurich
October 22, 1989	Depart Zurich en route to New York/Princeton

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